The Application of Petrology to Mineral Exploration: As inspired by Terry Leach

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What is Petrology ?

- The science that deals with the origin, history, occurrence, structure, and chemical classification of rocks
- The geological and chemical study of rocks.
- Scientific study of rocks that deal with their composition, texture, and structure; their occurrence and distribution; and their origin in relation to physicochemical conditions and geologic processes.
- The branch of geology that studies the origin, occurrence, and chemistry of rocks.
- Type of geology that deals with the formation, composition, and source of rocks. Person who studies in this discipline is a petrologist.
- The branch of geology that studies rocks: their origin and formation and mineral composition and classification
- Petrology (from Greek: πέτρα, petra, rock; and λόγος, logos, knowledge) is a field of geology that focuses on the study of rocks and the conditions on which they form.
- The branch of geology that deals with the origin, composition, structure, and alteration of rocks

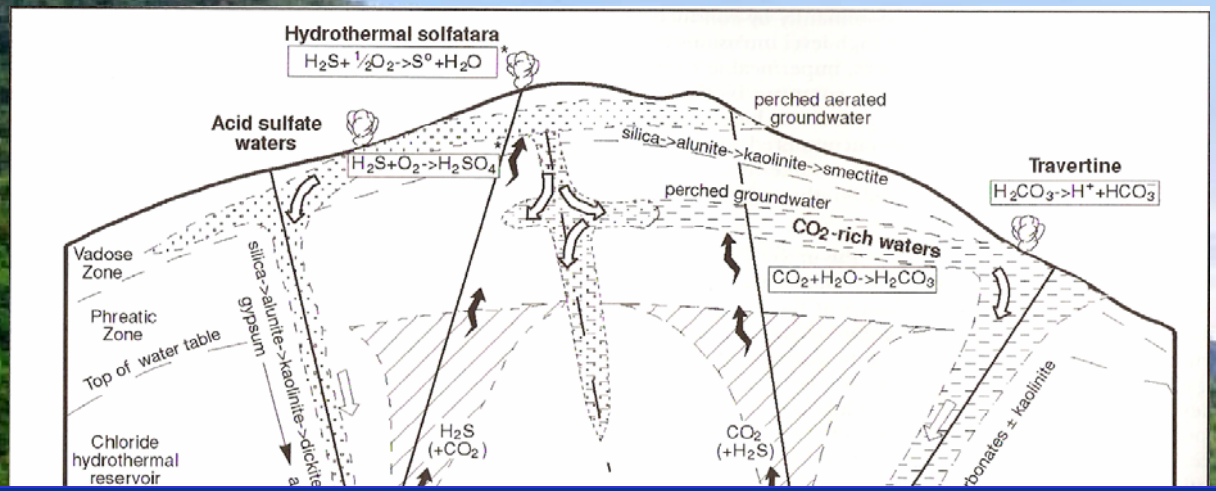
MOST GEOLOGISTS SHOULD THINK ABOUT PETROLOGY, SOME MAY SPECIALISE

Terry Leach inspired and pioneered successful specialist application of petrology to mineral exploration through:

- enthusiasm
- outstanding communication of data and ideas (ability to convey visualisation of data)
- an understanding of a broad range of mineral prospect/deposit styles.
- good observational skills and an empirical approach

Terry applied his knowledge of Philippine geothermal systems to understanding the hydrothermal environment and processes involved in the formation of hydrothermal ore deposits.

Hydrology and physiochemical zoning at shallow levels in geothermal systems.

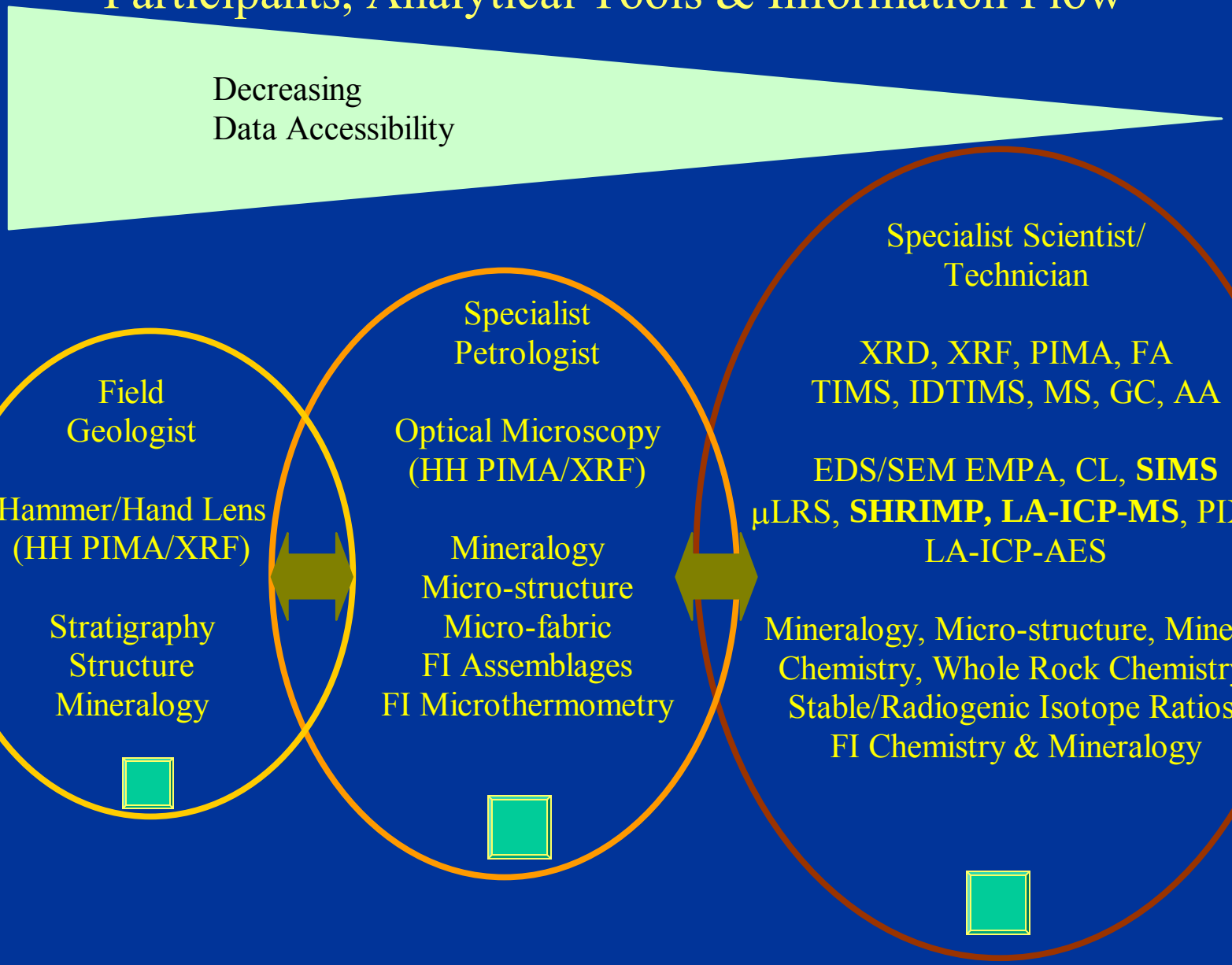


To follow:

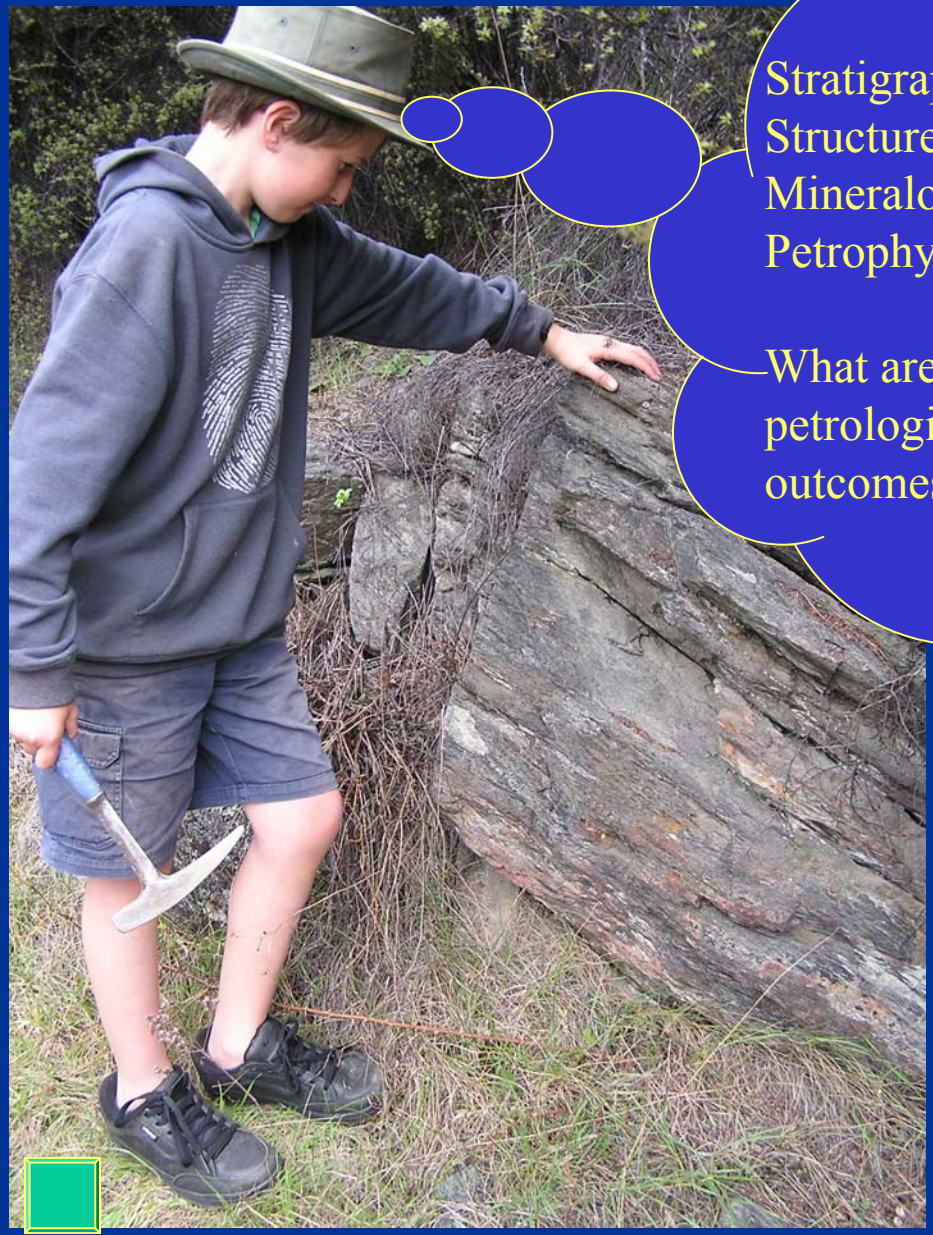
The **place and procedures of petrology** in mineral exploration today, as promoted by Terry with a focus on **advances in micro-analytical techniques** and their application to **copper-gold paragenesis** in **southwest pacific porphyry systems.**

Petrology in Mineral Exploration

Participants, Analytical Tools & Information Flow



Field Geologist: Hammer & Hand Lens



Stratigraphy ?
Structure ?
Mineralogy ?
Petrophysics ?

What are the possibilities for more detailed petrological work and what are the likely outcomes of benefit to exploration?

Specialist Petrologist: Optical Microscopy

Familiarity with the project ?
Site visit completed?
Mineralogy?
Micro-structure?
Micro-fabric?
FI Assemblages?
FI microthermometry?

Effective contribution to exploration programme within useful time frame

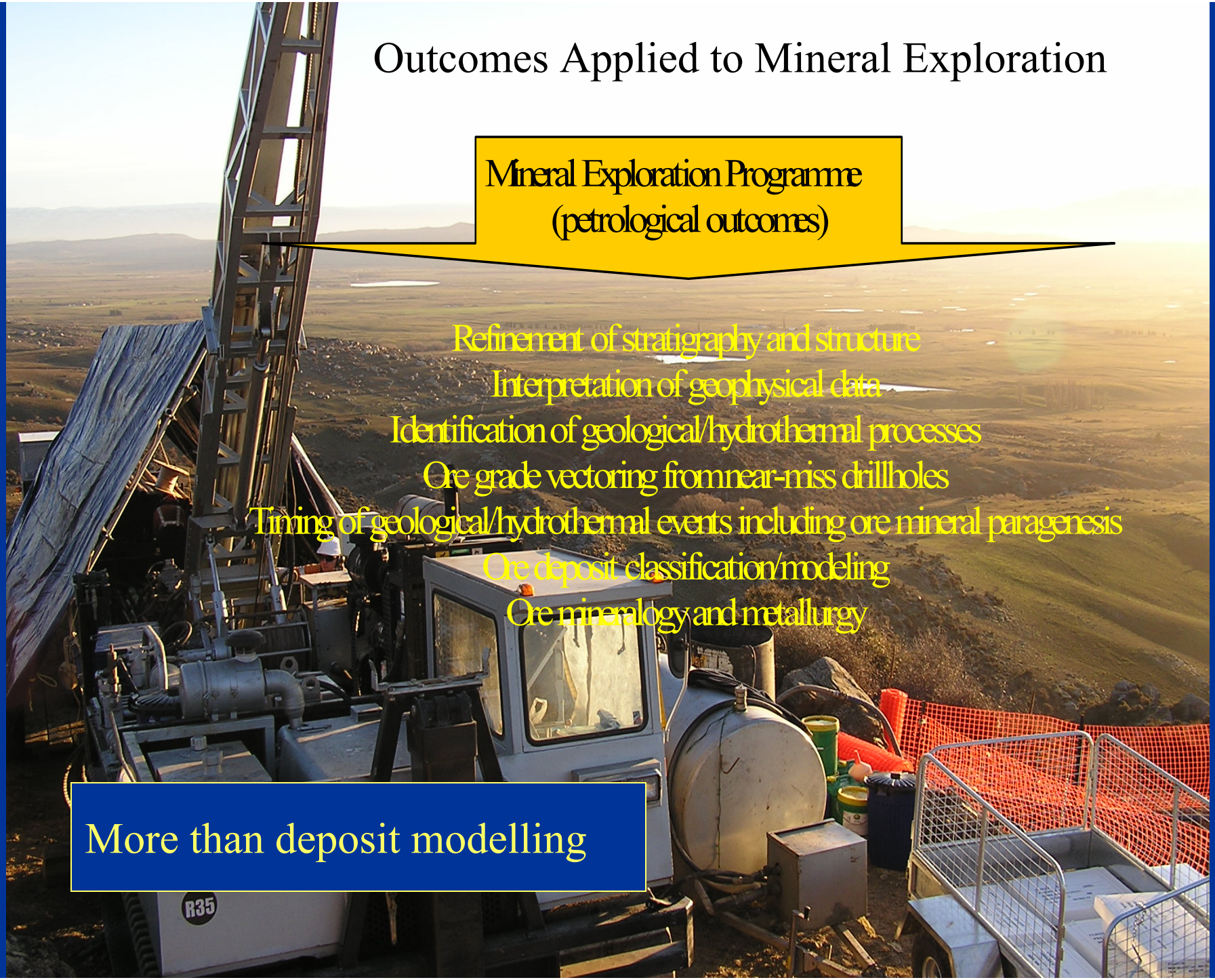
Specialist Scientist/technicion: Microanalytical Applications (Research Orientated)

Mineralogy, Mineral Chemistry
Whole Rock Geochemistry,
Micro-structure, FI Chemistry
& Mineralogy, Stable & Radiogenic
Isotope Ratios

Time constraints
Diminishing returns with time/$$ input

TIMS (Thermal Ionisation Multi-Collector, radiogenic isotope measurement from nanogram-size particles)
IDTIMS (Isotope Dilution thermal Ionisation Mass Spectrometry, for separation of single crystals; i.e. U/Pb in zircon)
SHRIMP (Sensitive High Mass-Resolution Ion Microprobe, in situ element and radiogenic isotope analysis)
LA-ICP-MS (Laser-Ablation Microprobe Inductively Coupled Plasma Mass Spectrometry, for in situ analysis, >2μm)
LA-ICP-AES (Laser Ablation Inductively Coupled Plasma Atomic Emission)
μLRS (Micro Laser Ramon Spectroscopy, in situ analysis of fluid inclusion mineralogy)
SIMS (Secondary Ion Mass Spectrometry, for high resolution sub-μm analysis of minerals and fluid inclusions)
GS (Gas Chromatography, in analysis of fluid inclusions)
PIXE (Proton Induced X-ray Emission Analysis, in analysis of fluid inclusions)

Outcomes Applied to Mineral Exploration



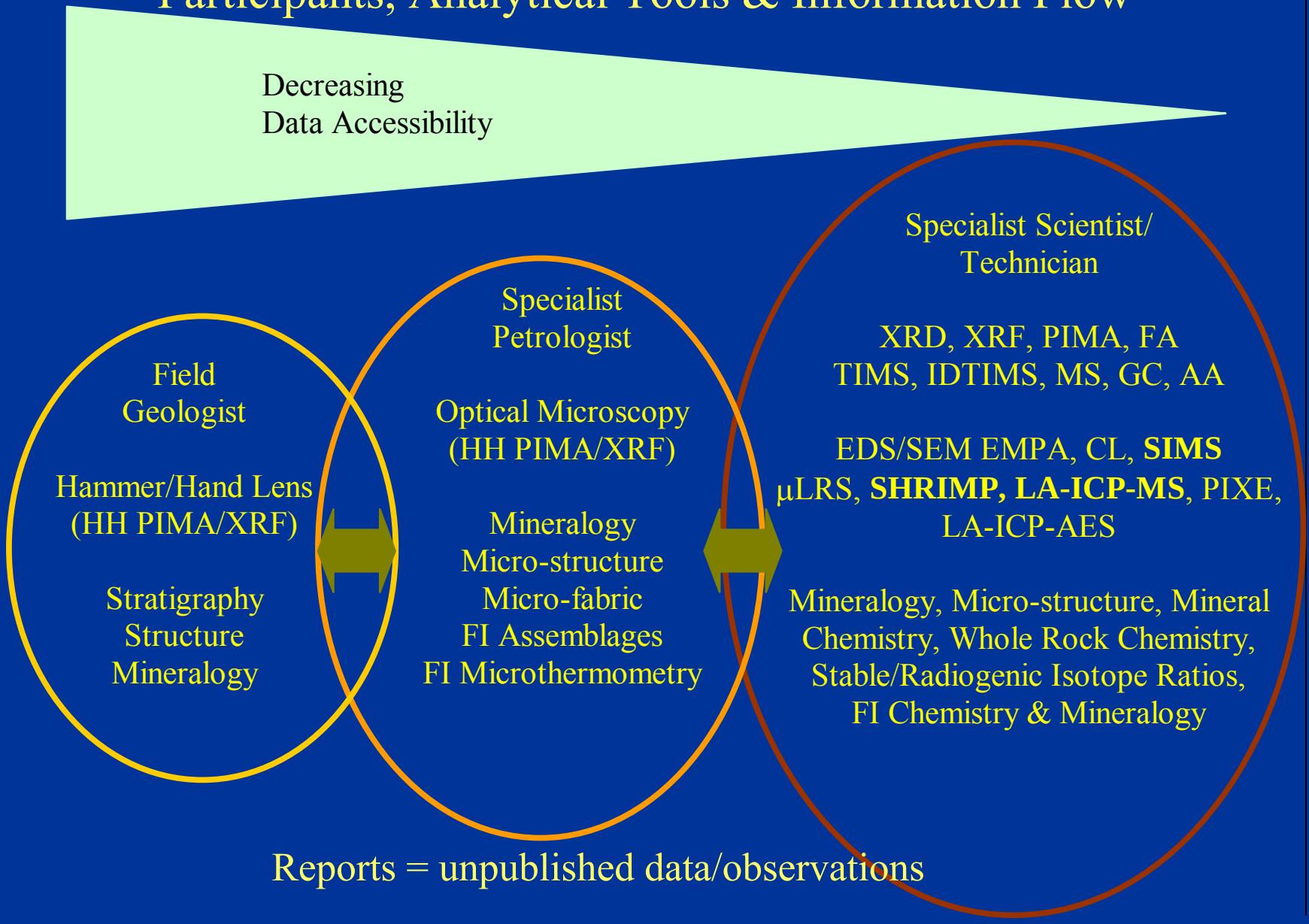
Mineral Exploration Programme (petrological outcomes)

Refinement of stratigraphy and structure
Interpretation of geophysical data
Identification of geological/hydrothermal processes
Ore grade vectoring from near-miss drillholes
Timing of geological/hydrothermal events including ore mineral paragenesis
Ore deposit classification/modeling
Ore mineralogy and metallurgy

More than deposit modelling

PETROLOGY IN MINERAL EXPLORATION

Participants, Analytical Tools & Information Flow



Reports = unpublished data/observations

ADVANCES IN PETROLOGY IN MINERAL EXPLORATION

Communication and data sharing, including the transfer of photomicrography readily placing microstructure and mineralogy in field context.

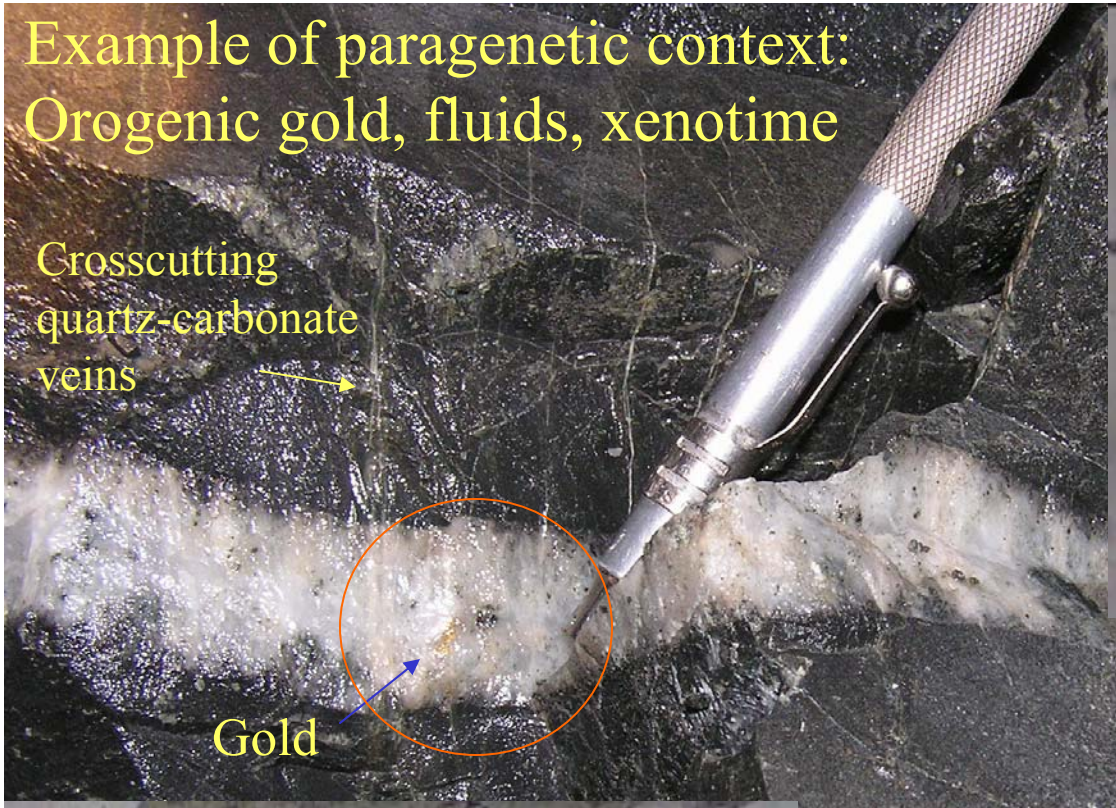
Hand held XRF and IR Spectral Analysis.

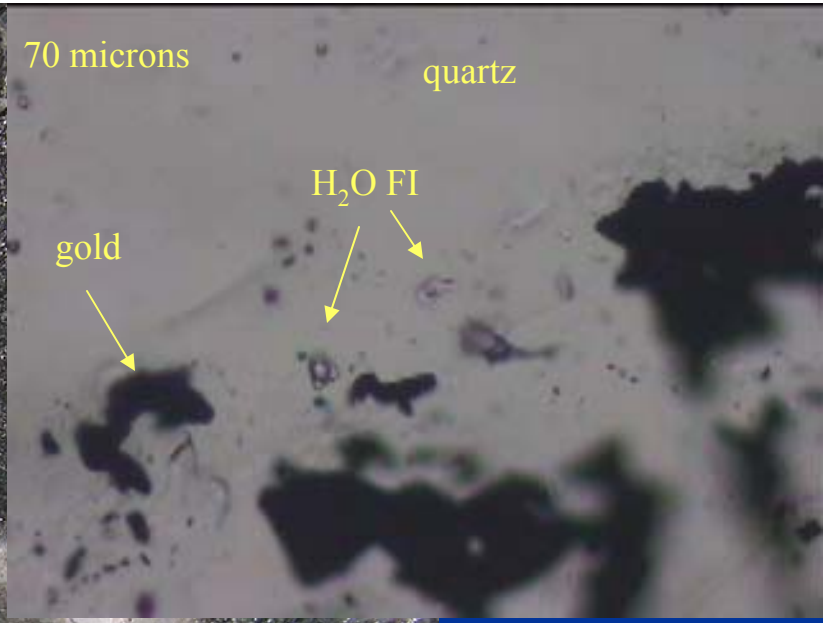
In situ micro-analytical techniques and applications (SIMS, SHRIMP LA-ICP-MS) that allow analysis of minerals and fluid inclusions in petrographic context:

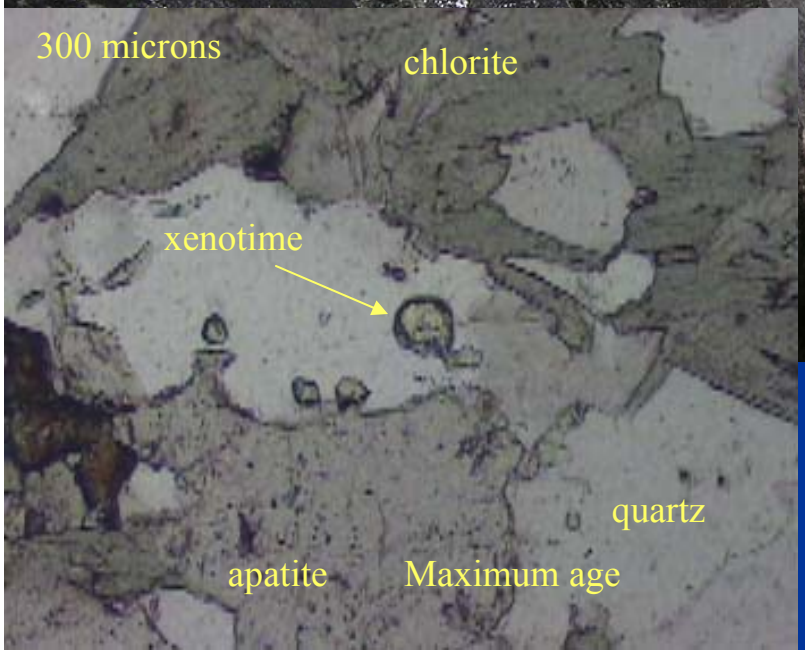
- Fingerprinting hydrothermal fluid source through stable isotope analysis of selected minerals and fluid inclusions.
- Chronology of fluids and ore minerals through selective radiogenic isotope analysis of minerals.
- Resolution of refractory ore and correlation of fluids/fluid inclusions with mineralisation.

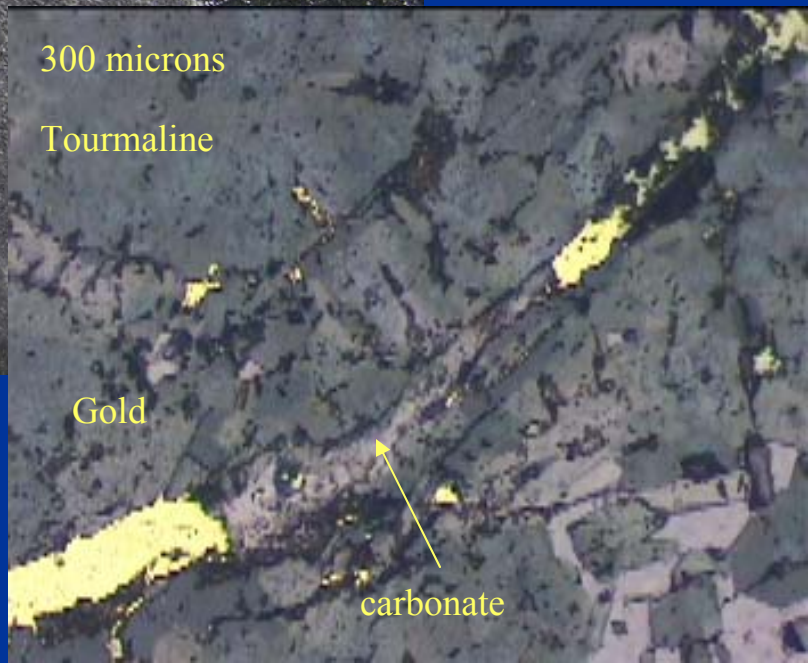
The applications of the in situ micro-analytical techniques are only as good as the field geology and optical microscopy providing paragenetic context of mineral and fluid inclusion assemblages.

Example of paragenetic context: Orogenic gold, fluids, xenotime

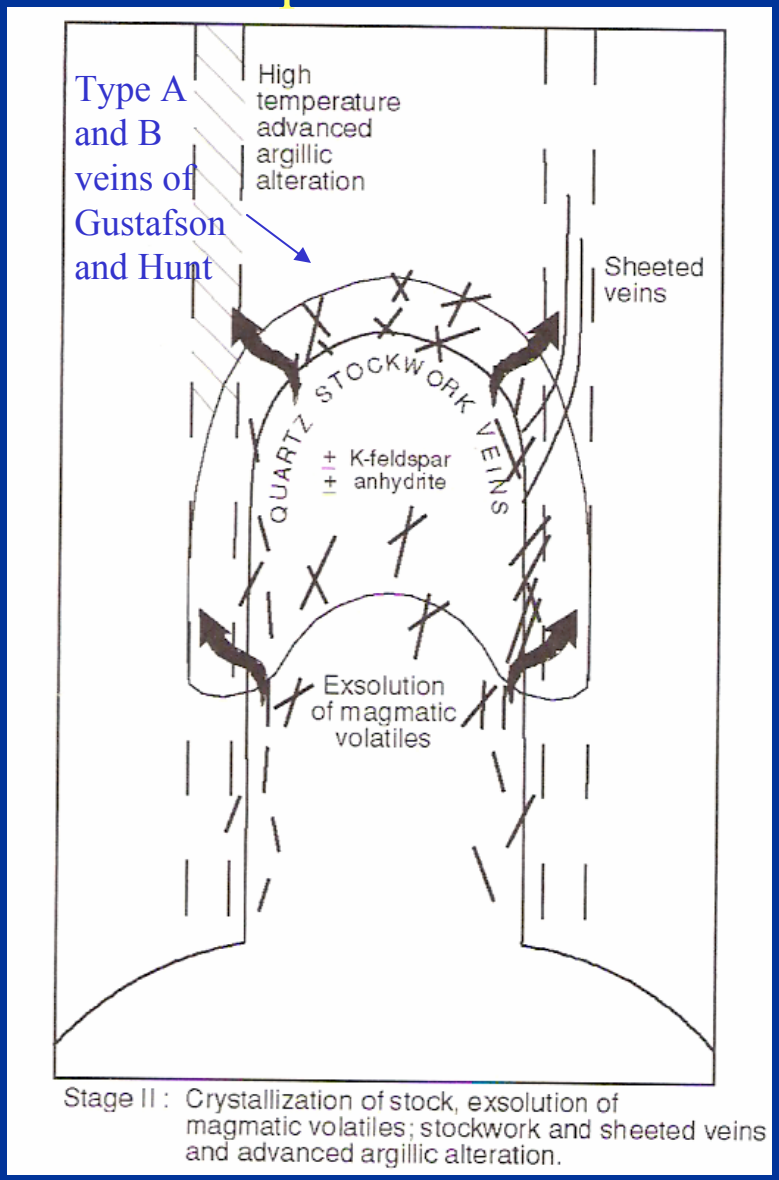






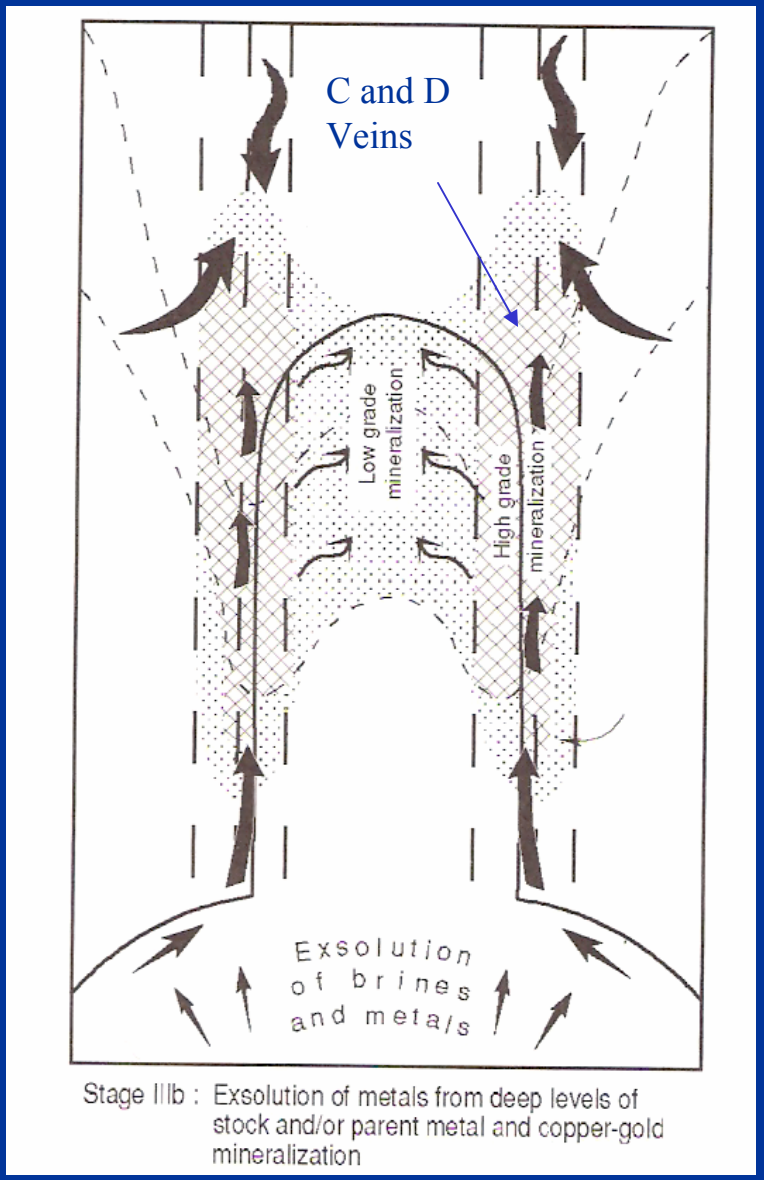


Western Pacific Porphyry Copper & Gold Model (Corbett & Leach, 1998)
A compilation of observations and available research



Stage II : Crystallization of stock, exsolution of magmatic volatiles; stockwork and sheeted veins and advanced argillic alteration.

Late Prograde



Stage IIIb : Exsolution of metals from deep levels of stock and/or parent metal and copper-gold mineralization

Late Retrograde

Western Pacific Porphyry Copper & Gold Model (Corbett & Leach, 1998)

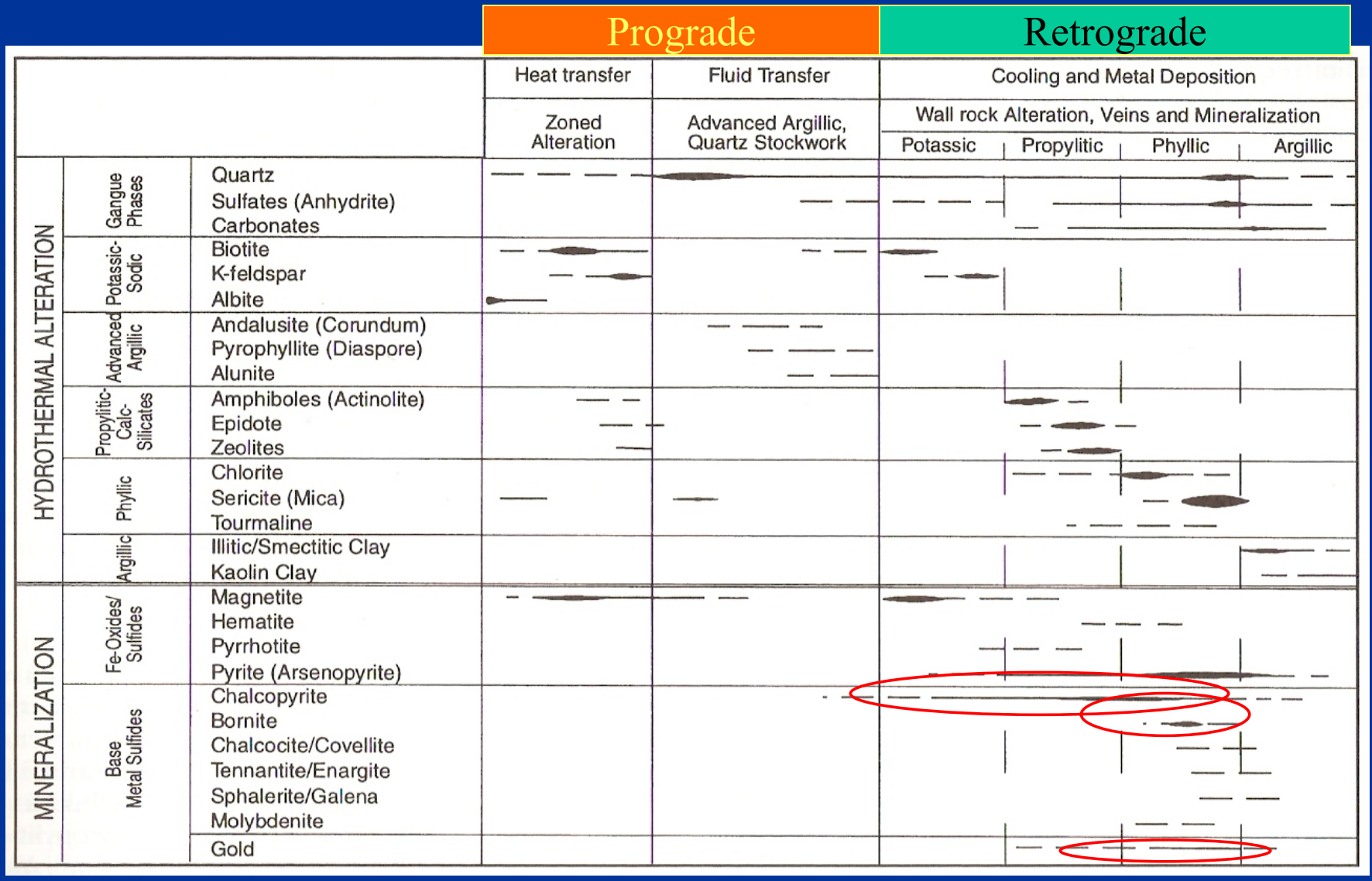


Figure 2. Paragenetic sequence in SW Pacific porphyry copper-gold systems (Corbett and Leach, 1998). Red enclosures indicate timing of main ore minerals.

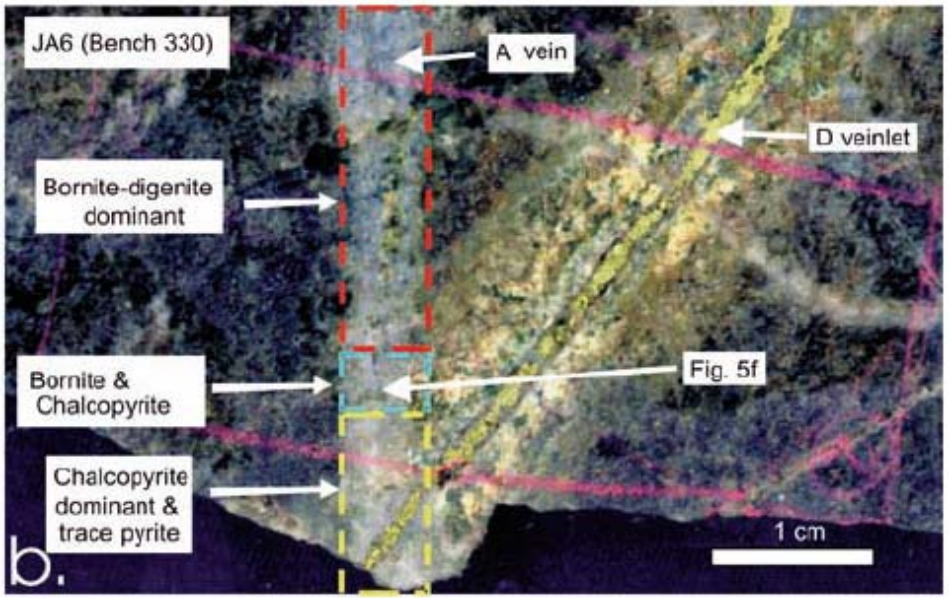
DETAILED MICRO-ANALYTICAL WORK OF THE LAST 10 YEARS (Corbett and Leach Model of 1998)

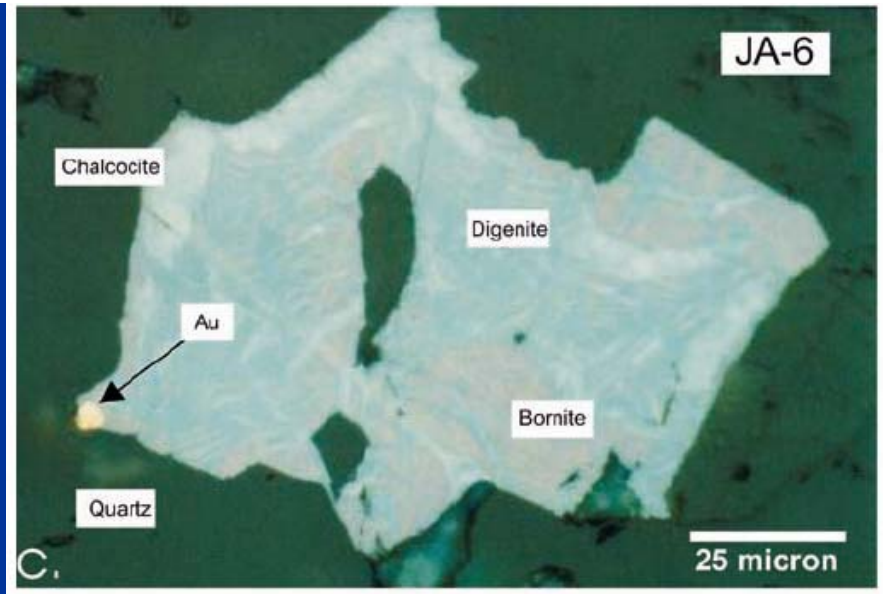
Studies mainly involving LA-ICP-MS analysis of mineral, melt and fluid inclusions, determine:

- Support for magmatic source of copper and gold with magmatic source controlling primary Cu/Au ratios and grade: the **incoming fluid magmatic hydrothermal fluid controls the overall metal budget of porphyry copper deposits**.

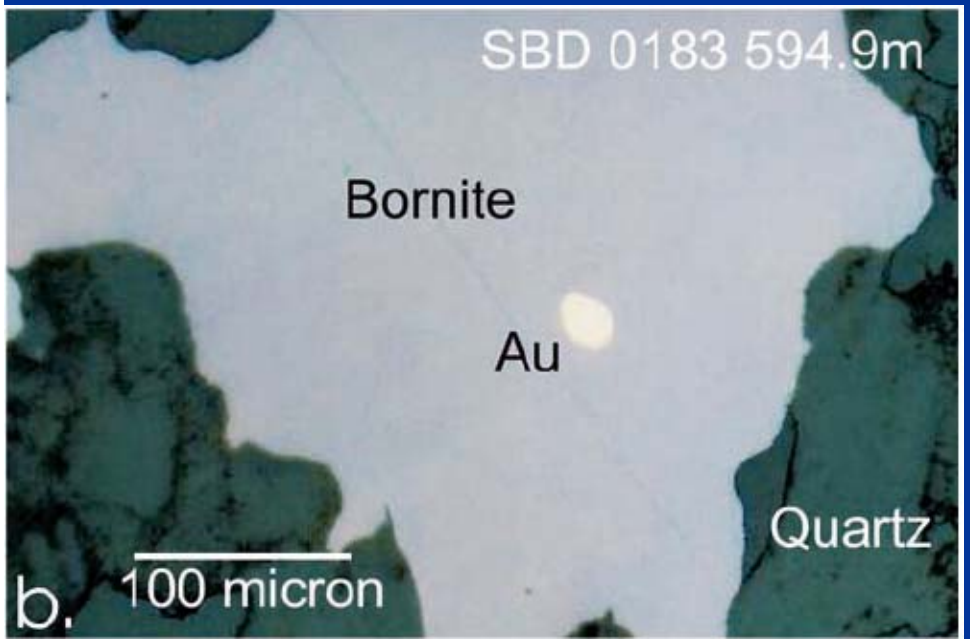
- Temperature controlled **copper and gold precipitation** from magmatic hydrothermal fluid can take place through the range **420 to 320 degrees C**.

- Copper and gold distribution in deposits including Batu Hijau finds **refractory and free gold associated with copper sulphides of prograde stage hydrothermal porphyry events** (Type A and B veins) as well as retrograde events.





Example of petrographically constrained detailed micro-analysis.
Batu Hijau Porphyry Cu/Au (Arif and Baker, 2004).



Consequences for the model

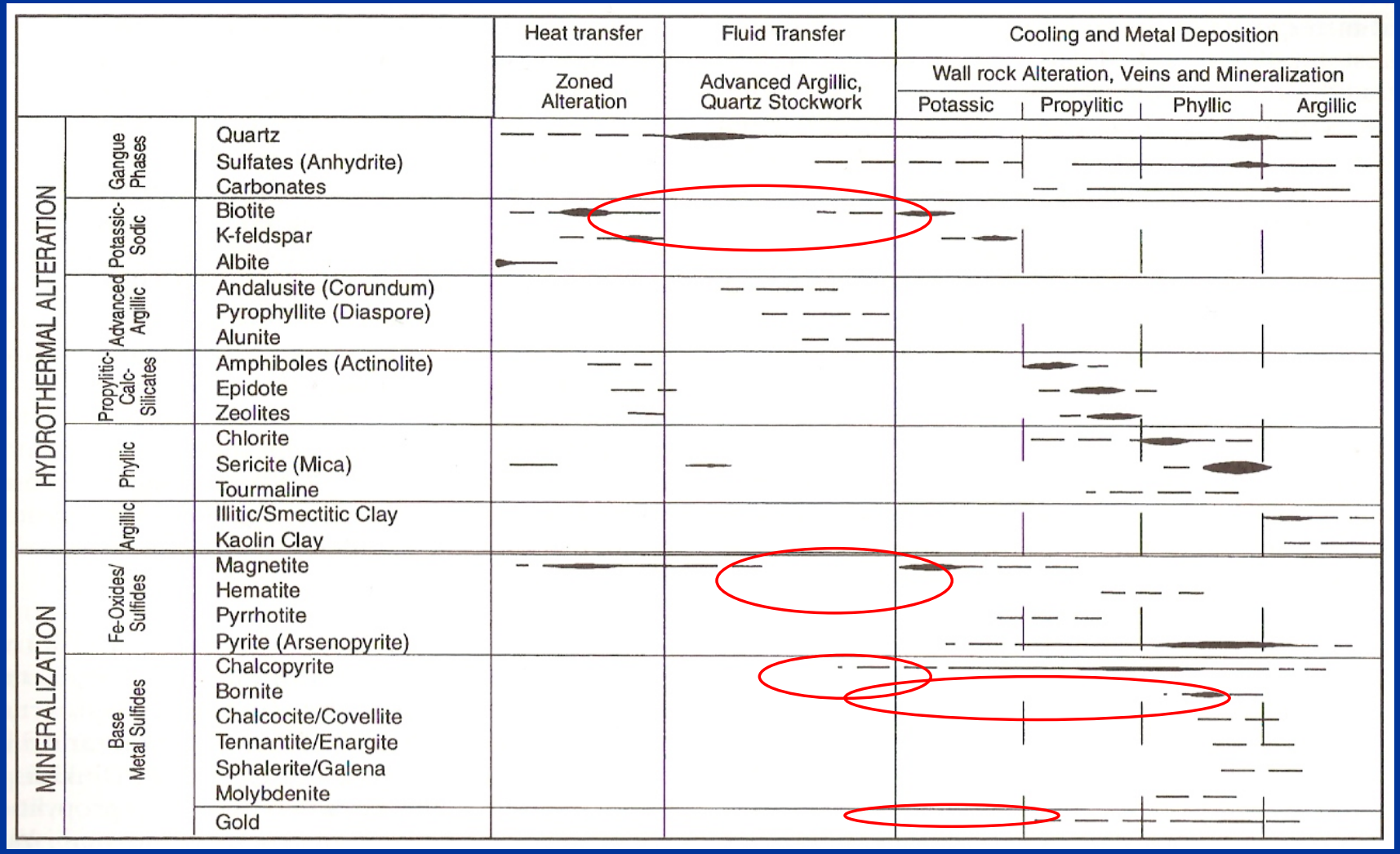
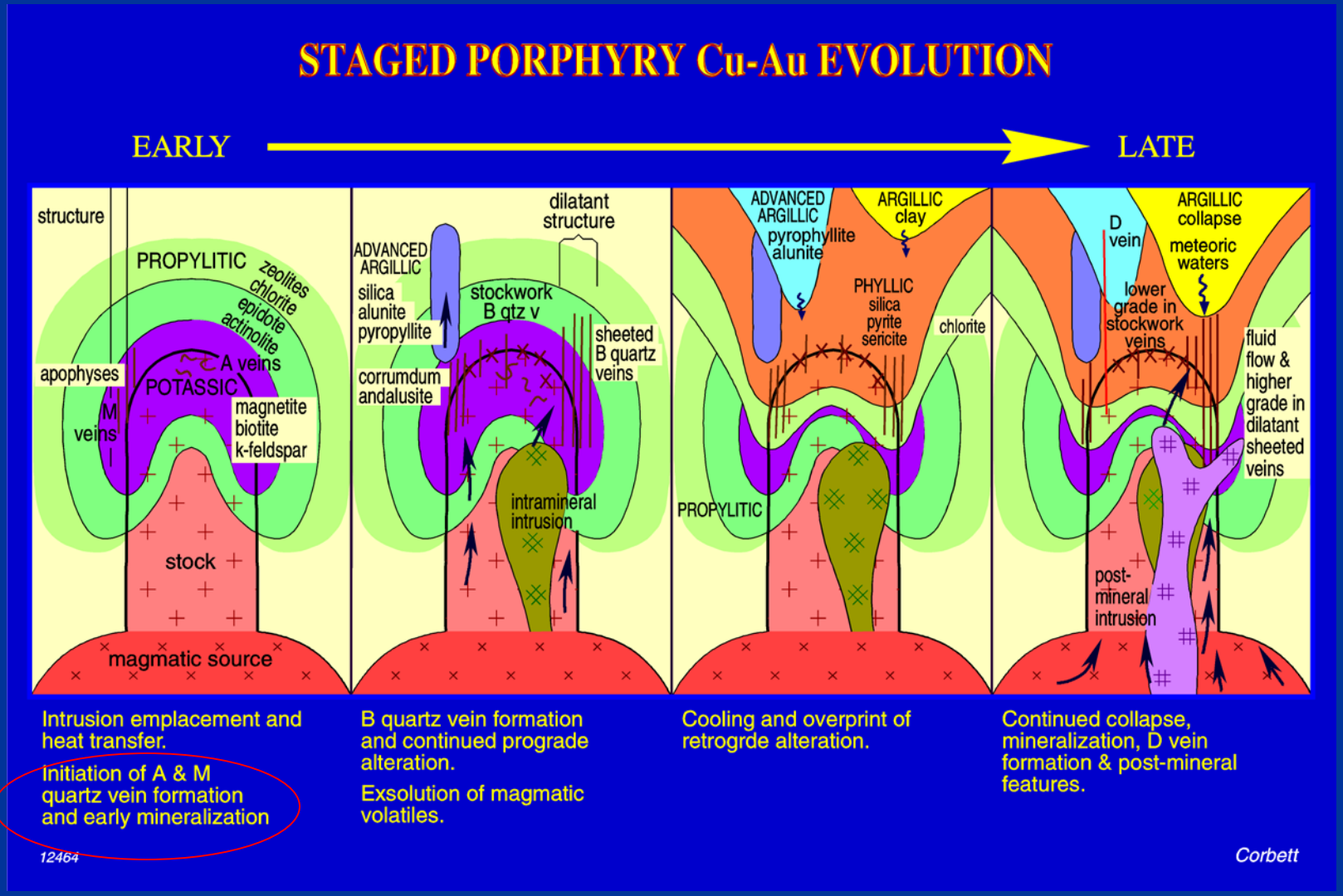


Figure 2. Paragenetic sequence in SW Pacific porphyry copper-gold systems (Corbett and Leach, 1998). Red enclosures indicate possible paragenetic extensions of indicated gangue and ore minerals.

Significance of copper and gold paragenesis to exploration



Structural and alteration vectors to mineralisation may be different depending on whether ore mineralogy is early or late

SUMMARY

Petrology encompasses the study and detailed mineralogical, chemical and structural description of rocks with a view to understanding the processes and the environment resulting in their formation.

The role of the specialist petrologist as promoted by Terry Leach, includes the provision of a time-constrained link between scientific research and effective mineral exploration strategy.

The understanding of copper and gold paragenesis within the porphyry environment has been advanced by the application of in-situ methods of microanalysis where target minerals and fluid inclusions remain in petrographic context.